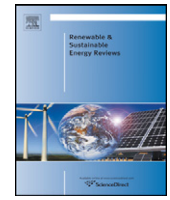
Renewable and Sustainable Energy Reviews 15 (2011) 2378–2384

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Evaluation of different diffuse radiation models for Indian stations and predicting the best fit model

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ARTICLE INFO

Article history:
Received 1 September 2010
Accepted 4 February 2011

Keywords:
Percent possible sunshine
Empirical models
Diffuse fraction
Clearness index
Parametric model
Decomposition model

ABSTRACT

In the present study, the non-linear solar radiation models for predicting the monthly average daily diffuse radiation are developed using the measured data on global radiation, diffuse radiation and sunshine hours for 12 locations of India. Statistical method is used to derive these correlations. The developed models are employed to estimate the monthly average daily diffuse radiation. The performance of these correlations is compared with existing model. Accuracy of developed relationships is also tested using statistical indicators viz. Percentage error (PE), root mean square error (RMSE), mean percentage error (MPE) and mean bias error (MBE). The study finds that these statistical parameters have very low values for the proposed models. A cubic correlation of diffuse coefficient with percent possible sunshine gives the best fit. The maximum values of RMSE, MPE and MBE for the proposed third order equation are 4.33%, 8.68% and −1.25% respectively while in the case of existing model these values are 13.28%, 13.39% and −3.83% respectively. Hence, it is possible to apply the cubic equation for the prediction of monthly mean daily diffuse radiation.

Contents

1. Introduction

The power obtained from solar radiation reaching the Earth is many times greater than the power generated by man by other conventional sources. If it is trapped in a useful and effective manner, all the present and future human energy needs may be met on a continual basis.

The energy received from the Sun is absorbed and also reflected back, a part of which is trapped in the atmosphere of the Earth. At any place the sum of direct and diffuse radiation is known as global or total radiation. Solar energy can be utilized for different applications by a suitable choice of tapping device. The availability of solar radiation will depend on place, on tilt of the surface on which it is received and also upon a number of other factors.

Since the solar radiation reaching the Earth's surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is necessary. This knowledge of local solar-radiation is essential for the proper design of buildings, energy systems, solar energy systems and a good evaluation of thermal environment within buildings [1–6]. It is measured in terms of sunshine duration or in terms of direct, diffuse and global radiation. In the absence of solar radiation data, the need for an empirical model for prediction of solar radiation is desirable.

Solar radiation models are of two categories namely parametric model in which detailed information of atmospheric conditions is required and decomposition models which require global radiation for the estimation of direct and diffuse component [7]. The

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doi:10.1016/j.rser.2011.02.020

metrological parameters such as amount and distribution of clouds, fractional sunshine, atmospheric turbidity and perceptible water content are used in parametric models [8].

Several empirical correlations have been developed to estimate solar radiation [9–16]. Orgill and Hollands [17] have used the following diffuse radiation model based on the hourly data of Toronto (Canada) correlating the diffuse fraction K_d and clearness index K_T:

$$\frac{H_d}{H_g} = 1 - 0.249\,K_T, \quad K_T < 0.35$$

$$\frac{H_d}{H_g} = 1.577 - 1.84\,K_T, \quad 0.35 \le K_T \le 0.75$$

$$\frac{H_d}{H_g} = 0.177, \quad K_T > 0.75 \tag{a}$$

Erbs et al. [18] studied the data from location of USA and have given the relations as:

$$\frac{H_d}{H_g} = 1 - 0.09\,K_T, \quad K_T \le 0.22$$

$$\frac{H_d}{H_g} = 0.9511 - 0.1604\,K_T + 4.388\,K_T^2 + 16.638\,K_T^3 + 12.336\,K_T^4,$$
$$0.22 \le K_T 0.22 \le 0.8$$

$$\frac{H_d}{H_g} = 0.165, \quad K_T > 0.8 \tag{b}$$

Reindl et al. [19] proposed two models for hourly diffuse radiation using the data of USA and Europe. The first model is in terms of clearness index and is given by:

$$\frac{H_d}{H_g} = 1.02 - 0.248\,K_T, \quad K_T \le 0.3$$

$$\frac{H_d}{H_g} = 1.45 - 1.67\,K_T, \quad 0.3 < K_T < 0.78 \tag{c}$$

The second model has been given in terms of clearness index and solar elevation α and is as follow:

$$\frac{H_d}{H_g} = 1.02 - 0.248\,K_T + 0.0123\,\sin\alpha, \quad K_T \le 0.3$$

$$\frac{H_d}{H_g} = 1.4 - 1.749\,K_T + 0.177\,\sin\alpha, \quad 0.3 < K_T < 0.78$$

$$\frac{H_d}{H_g} = 0.486\,K_T - 0.182\,\sin\alpha, \quad K_T \ge 0.78 \tag{d}$$

Lam and Li [20] have developed following relationship for the prediction of hourly diffuse components of global radiation for Hong Kong.

$$\frac{H_d}{H_g} = 0.977, \quad K_T \le 0.15$$

$$\frac{H_d}{H_g} = 1.237 - 1.361\,K_T, \quad 0.15 < K_T \le 0.7$$

$$\frac{H_d}{H_g} = 0.273, \quad K_T > 0.7 \tag{e}$$

Mondel et al. [21] have presented diffuse-global model using the hourly data for Northen Ireland as:

$$\frac{H_d}{H_g} = 1.237 - 1.361\,K_T,$$

$$\frac{H_d}{H_g} = 0.61092 + 3.6259\,K_T - 10.171\,K_T^2 + 6.338\,K_T^3,$$
$$0.2 < K_T \le 0.7$$

$$\frac{H_d}{H_g} = 0.672 - 0.474\,K_T, \quad K_T > 0.7 \tag{f}$$

Studies [22–24] have also been made to estimate hourly diffuse solar radiation based on artificial neural network technique. Liu and Jorden [25] have developed model for estimating the diffuse components of daily global radiation which is given by:

$$\frac{H_d}{H_g} = 0.384 - 0.416 K_T, \tag{g}$$

Spencer [26] studied the mean daily data from the localities in Australia and proposed following latitude (ϕ) dependent relationship between diffuse fraction of global radiation and clearness index.

$$\frac{H_d}{H_g} = a - b \quad K_T, \quad 0.35 \le K_T \le 0.75$$

where,

$$a = 0.94 + 0.0118|\phi|, \quad b = 1.185 + 0.0135|\phi|, \tag{h}$$

Boland et al. [27] have given a logistic function of the form $f(x) = a_o/1 + a_1 e^{a_2 x}$ for estimating diffuse solar radiation for Australian condition and Jacovides et al. [28] have proved its validity for locations in Cyprus.

The objective of the work reported in this paper is the development of non-linear relations for estimating the diffuse component of global radiation on a horizontal surface and to compare these relationships with the calculations based on existing model and then to find out the most suitable correlation for computing diffuse radiation for locations in India. The monthly average data of solar radiation are employed in partial regression analysis to derive the models.

2. Methodology

Despite using different approaches almost all the authors viz. Page [29], Gupta et al. [30], Modi and Sukhatme [31], Mani and Rangrajan [32] and Gopinathan [33] have given following linear equation for the estimation of monthly mean daily diffuse radiation:

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) \tag{1}$$

where H_d is the monthly mean daily diffuse radiation on a horizontal surface in kWh/m^2, H_g is the monthly mean daily global radiation on a horizontal surface in kWh/m^2 and H_o is the monthly mean of extra-terrestrial radiation in kWh/m^2. a and b are correlation coefficients.

In our study, the experimental data on global radiation, diffuse radiation and sunshine hours reported by Mani and Rangarajan [34] have been analyzed for 14 locations of India. We have taken a group of following relation:

(i) models correlating diffuse fraction H_d/H_g with clearness index K_T and fraction of possible number of sunshine S/S_{max}

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{S}{S_{max}}\right) \tag{2}$$

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{H_g}{H_o}\right)^2 \tag{3}$$

Table 1
Regression coefficients for the chosen locations.

Stations	For third order equation				For second order Equation		
	a	*b*	*c*	*d*	*a*	*b*	*c*
Ahmadabad	0.5456	−1.1613	1.744	−0.9945	–	–	–
Bhavnagar	0.308	0.068	−0.078	−0.155	0.28	0.236	−0.37
Mumbai	0.3509	−0.4695	1.0988	−0.9116	–	–	–
Kolkata	0.3401	−0.3815	0.8308	−0.6857	0.2378	0.2387	−0.3323
Goa	0.2537	0.1737	−0.0495	−0.2947	1.0654	−0.345	−0.6604
Jodhpur	−0.0684	1.8254	−2.7068	1.085	0.35	0.0459	−0.2672
Madras	0.2753	0.3472	−0.9128	0.4683	0.4195	−0.3099	0.0597
Nagpur	0.3181	−0.0986	0.0422	−0.1253	0.2957	0.0334	−0.1895
New Delhi	0.7863	−2.0503	2.7041	−1.3029	0.3887	−0.2137	−0.0174
Pune	0.1982	0.8814	−1.7625	0.8095	0.4113	−0.2313	−0.0575
Tiruvanantpuram	0.3751	−0.2126	0.0570	−0.0980	0.3350	−0.0344	0.1838
Vishahapatanam	0.3503	−0.1720	−0.0068	−0.0119	0.3426	−0.1405	−0.0435

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{H_g}{H_o}\right)^2 + d\left(\frac{H_g}{H_o}\right)^3 \tag{4}$$

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{H_g}{H_o}\right)^2 + d\left(\frac{H_g}{H_o}\right)^3 + e\left(\frac{H_g}{H_o}\right)^4 \tag{5}$$

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{H_g}{H_o}\right)^2 + d\left(\frac{H_g}{H_o}\right)^3 + e\left(\frac{H_g}{H_o}\right)^4 + f\left(\frac{H_g}{H_o}\right)^5 \tag{6}$$

(ii) models correlating diffuse coefficient H_d/H_o with fraction of possible number of sunshine S/S_{max}

$$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2 \tag{7}$$

$$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2 + d\left(\frac{S}{S_{max}}\right)^3 \tag{8}$$

Here S is monthly mean of sun-shine hours per day and S_{max} is monthly mean of maximum possible sun-shine hours per day and a, b, c, d, e and f are the regression coefficients. The no. of regression coefficients changes with the order of the equation.

We have used partial regression analysis. The experimental data of each station are used in normal equations and statistical analysis is carried out to find the regression coefficients from the above relations (from Eqs. (2) to (8)) for each station. The regression coefficients of Eq. (1) are also computed for each of the 12 locations. A comparison is then made between the results obtained on the basis of Eq. (1) and above proposed models (from Eqs. (2) to (8)).

3. Statistical parameters

The statistical parameters have been used to evaluate the performance of the formerly given different models (Eqs. (1)–(8)) for each station. These are – percentage error (PE), mean percentage error (MPE), root mean square error (RMSE) and mean bias error (MBE). We have expressed RMSE and MBE as percentage.

The percentage error

$$PE = \left(\frac{H_{do} - H_{dc}}{H_{do}}\right) \times 100 \tag{9}$$

is calculated for each month of the year for all the proposed models and also for relation given by Eq. (1). H_{go} is the observed and H_{gc} the calculated value of diffuse radiation. The mean percentage error is also computed.

$$MPE = \left[\frac{\sum(H_{do} - H_{dc}/H_{do}) \times 100}{n}\right] \tag{10}$$

The accuracy of these relationship**s** is also tested by calculating RMSE and MBE. These are defined as:

$$RMSE = \left\{\frac{[\sum(H_{i,c} - H_{i,o})^2]}{n}\right\}^{1/2} \tag{11}$$

$$MBE = \frac{[\sum(H_{i,c} - H_{i,o})]}{n} \tag{12}$$

where $H_{i,c}$ is the ith calculated value, $H_{i,o}$ is the ith measured value and n is the number of observations.

RMSE provides information on the short-term performance of a model. The lower the RMSE, the more accurate is the estimation [21]. MBE provides information on the long-term performance of a model. Positive and negative MBE values show overestimation and underestimation respectively [21].

To check the linearity between the estimated and observed values, coefficient of determination R^2 is used.

4. Results and discussions

Using partial regression analyses, the data on H_d, H_g and S for the 12 locations are analyzed and statistical analyses is carried out. The comparison between experimental and computed values of diffuse radiation from Eqs. (2)–(8) is made. We found that for Ahmadabad and Mumbai model 8 gives better results than that of other equations. So for these two stations cubic relation between diffuse coefficient (H_d/H_o) and fraction of possible number of sunshine (S/S_{max}) (Eq. (8)) must be used.

Good agreement between the observed and estimated diffuse radiation from Eqs. (7) and (8) and is found for the stations Bhavnagar, Kolkata, Goa, Jodhpur, Madras, Nagpur, New Delhi, Pune, Tiruvanantpuram and Vishakhapatanam, in comparison to the other model (i.e. Eq. (1)). Hence square and cubic relation between

Table 2
RMSE (%) for the proposed cubic and square correlation.

Stations	Third order equation	Second order equation	Eq. (1)
Ahmadabad	1.73	–	10.4
Bhavnagar	0.58	0.58	5.2
Mumbai	0.58	–	8.08
Kolkata	4.33	4.91	9.53
Goa	2.31	2.31	4.62
Jodhpur	2.6	2.6	8.37
Madras	0.29	0.29	2.6
Nagpur	2.31	2.6	3.75
New Delhi	2.89	2.31	13.28
Pune	2.89	2.89	7.22
Tiruvanantpuram	0.87	0.87	2.31
Vishahapatanam	0.87	0.87	1.15

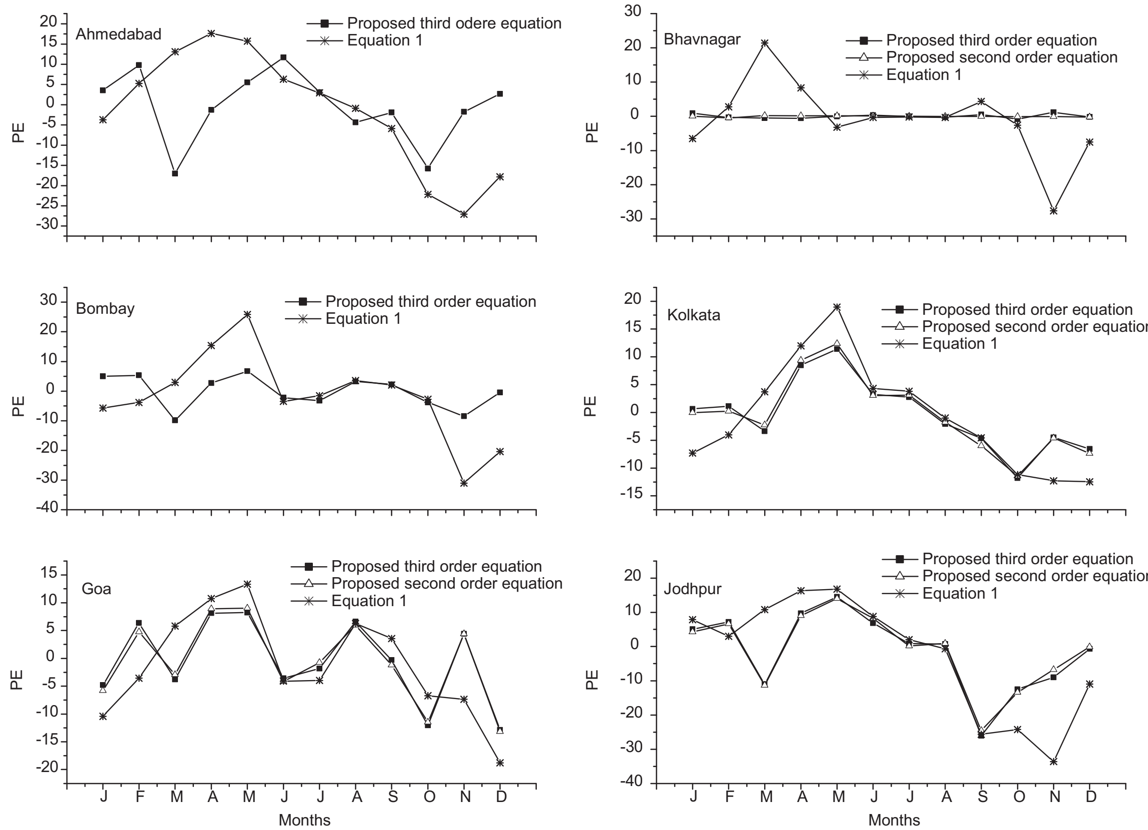

Fig. 1. Comparative plot of the percentage error for the proposed models and for Eq. (1) for Ahmadabad, Bhavnagar, Mumbai, Kolkata, Goa and Jodhpur.

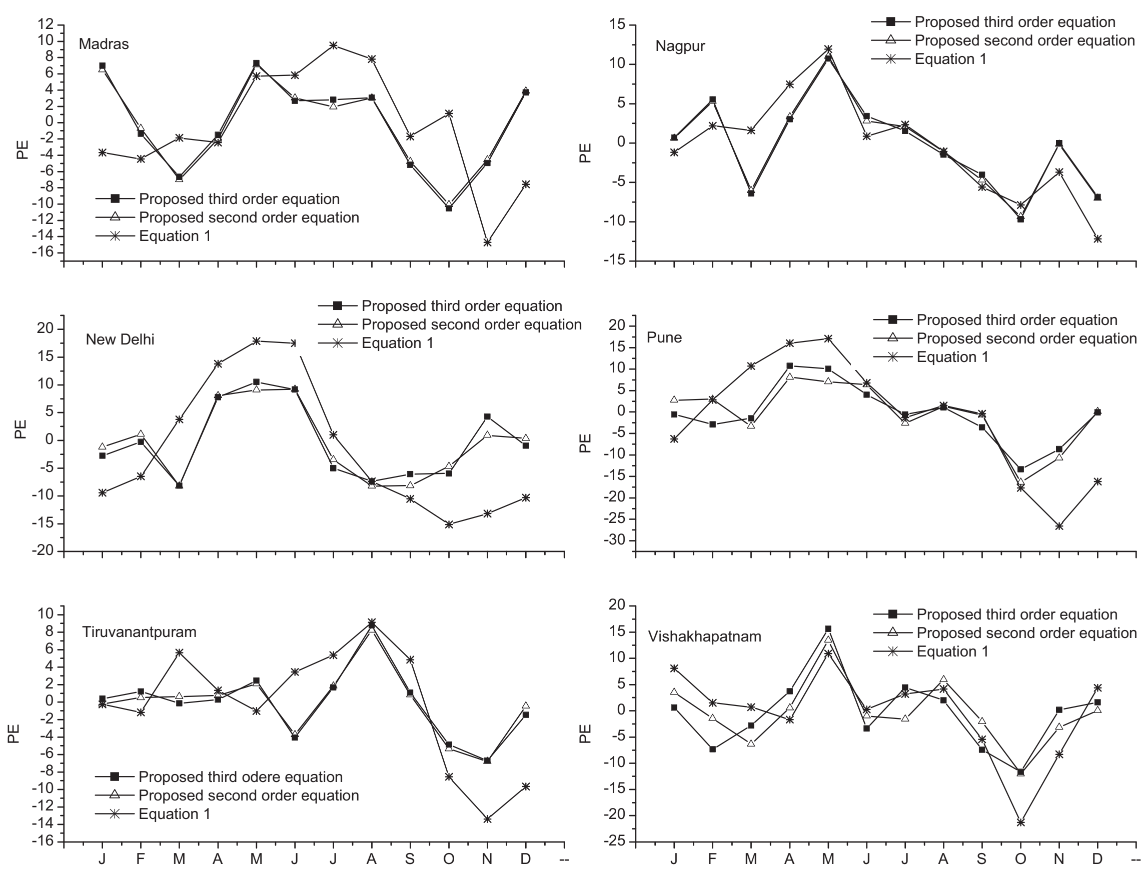

Fig. 2. Comparative plot of the percentage error for the proposed models and for Eq. (1) for Madras, Nagpur, New Delhi, Pune, Tiruvanantpuram and Vishakhapatanam.

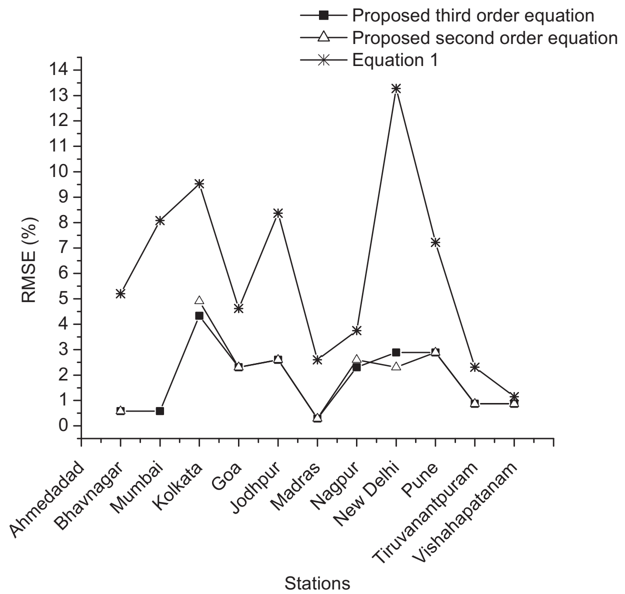

Fig. 3. RMSE (%) for the proposed third order equation, second order equation and for Eq. (1).

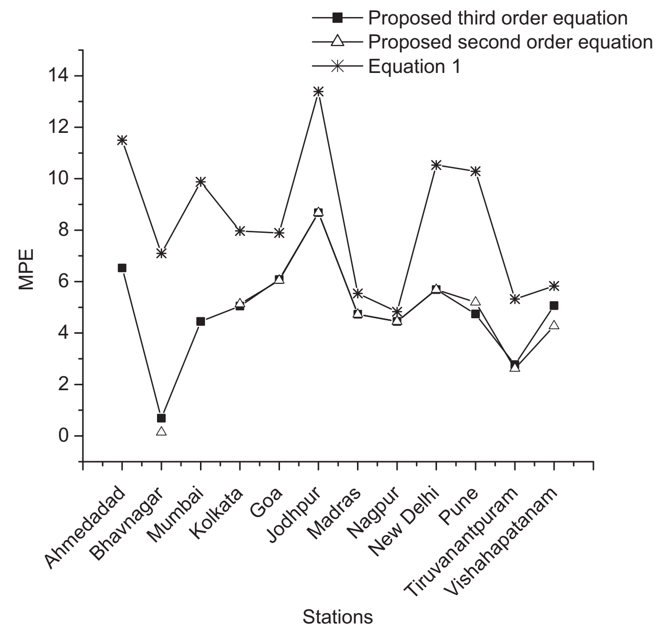

Fig. 4. MPE for the proposed third order equation, second order equation and for Eq. (1).

diffuse coefficient and percent possible sunshine (i.e. Eqs. (7) and (8)) must be applied for these locations. The regression coefficients of the proposed equations for each station are found out which are listed in Table 1.

It is clear that second and third-order equation between diffuse coefficient H_d/H_o and percent possible sunshine S/S_{max} are fit for all the considered stations. Thus these square and cubic relations can be used for majority of locations in India.

To check the accuracy of these relationships plots of percentage errors (PE) for the proposed models and that of Eq. (1) are drawn for each location. These are shown in Figs. 1 and 2. For Ahmadabad, Bhavnagar, Mumbai, Kolkata, Goa and Jodhpur percentage errors are illustrated in Fig. 1 while for the other six locations Madras, Nagpur, New Delhi, Pune, Tiruvanantpuram and Vishapatanam these are shown in Fig. 2.

RMSE (%) for the proposed cubic equation, second order equation and that of Eq. (1) is tabulated in Table 2 and plotted in Fig. 3. Mean percentage error (MPE) for these two models along with the widely used relationship (Eq. (1)) is illustrated in Table 3 and Fig. 4. Plots are also drawn for percentage MBE (listed in Table 4) which are shown in Fig. 5.

For the 12 locations, the percentage errors as shown in Figs. 1 and 2 give the comparison between PE from the proposed models and from the relation given by Eq. (1). Fig. 1 indicates that percentage error for calculations based on Eq. (1) are higher com-

Table 3
MPE for the proposed cubic and square correlation.

Stations	Third order equation	Second order equation	Eq. (1)
Ahmadabad	6.53	–	11.5
Bhavnagar	0.69	0.14	7.1
Mumbai	4.45	–	9.88
Kolkata	5.05	5.13	7.97
Goa	6.08	6.05	7.89
Jodhpur	8.68	8.68	13.39
Madras	4.73	4.73	5.54
Nagpur	4.45	4.45	4.83
New Delhi	5.69	5.69	10.53
Pune	4.74	5.2	10.29
Tiruvanantpuram	2.77	2.62	5.32
Vishahapatanam	5.07	4.27	5.83

Table 4
MBE (%) for the proposed cubic and square correlation.

Stations	Third order equation	Second order equation	Eq. (1)
Ahmadabad	−0.5	–	−3
Bhavnagar	0.17	0.17	−1.5
Mumbai	−0.17	–	−2.3
Kolkata	−1.25	−1.42	−2.75
Goa	−0.67	−0.67	−1.33
Jodhpur	−0.75	−0.75	−2.42
Madras	0.08	0.08	0.75
Nagpur	−0.67	−0.75	−1.08
New Delhi	−0.83	−0.83	−3.83
Pune	−0.83	−0.83	−2.08
Tiruvanantpuram	−0.25	−0.25	−0.67
Vishahapatanam	−0.25	−0.25	−0.33

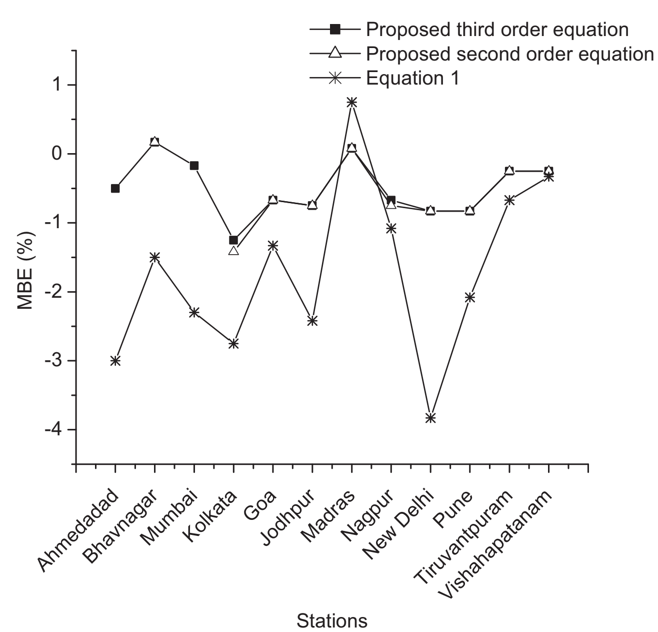

Fig. 5. MBE (%) for the proposed third order equation, second order equation and for Eq. (1).

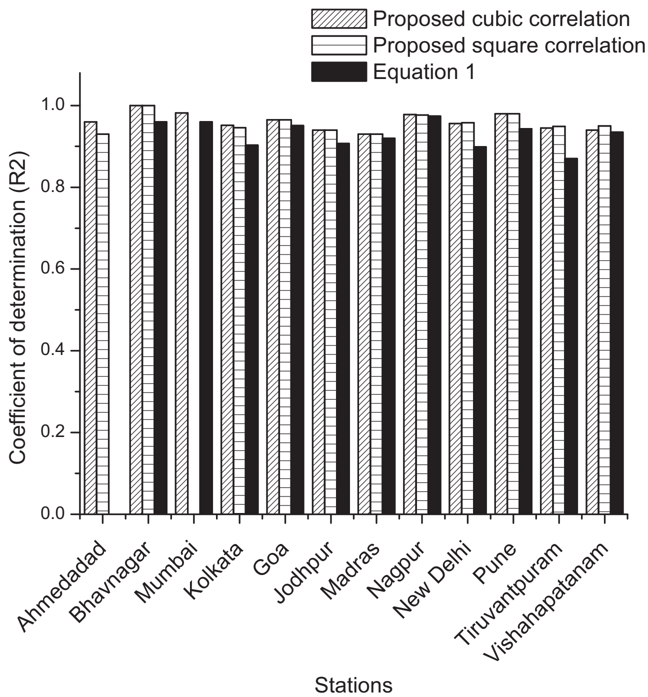

Fig. 6. Coefficient of determination R^2 for the considered locations.

pared to the proposed models for all the six stations (Ahmadabad, Bhavnagar, Mumbai, Kolkata, Goa and Jodhpur) and in the case of Bhavnagar, these errors are comparatively high. Fig. 2 (for Madras, Nagpur, New Delhi, Poona, Tiruvanantpuram and Vishapatanam) also gives the similar results. Although for some of the months of the year, errors from the proposed models are slightly greater than the widely used relation (Eq. (1)), but on average, errors (%) from Eq. (1) are significantly higher than that of our models for all the 12 stations.

The RMSE varies between 0.29% (Madras) and 4.33% (Kolkata) for the proposed cubic model while for Eq. (1); it has values between 1.15% (Vishakhapatanam) and 13.28% (New Delhi) as clear from Fig. 3. It is found that root mean square error for the proposed third order relation is lower than that of Eq. (1) for all the locations. RMSE for the second order proposed relation ranges from 0.29% (Madras) to 4.91% (Kolkata). Again for widely used relation (Eq. (1)) it has higher values than that of second order equation as illustrated in Fig. 3. The lower RMSE values of third and second order proposed equation demonstrate their accuracy compared to Eq. (1).

Fig. 4 shows that MPE values have the range 0.69% (Bhavnagar) to 8.68% (Jodhpur) for our cubic equation and 0.14% (Bhavnagar) to 8.68% (Jodhpur) for the second order equation proposed by us. While for the relation given by Eq. (1) the values vary between 4.83% (Nagpur) and 13.39% (Jodhpur). Although for some months of the year, percentage errors from proposed models slightly exceed the errors from Eq. (1), it is clear from figure that mean percentage error (MPE) has comparatively lower values for our proposed models than that of the widely used equation (Eq. (1)) for all stations.

The MBE values lie from 0.08% (Madras) to −1.25% (Kolkata) for the third order equation and from 0.17% (Bhavnagar) to −1.42% (Kolkata) for our second order proposed equation as illustrated in Fig. 5. For model given by Eq. (1), these values vary between −0.33% (Vishakhapatanam) and −3.83% (New Delhi). It is clear that for Eq. (1), MBE values are higher compared to our proposed models for all stations which lead the long term performance of our proposed models.

The coefficient of determination R^2 for the chosen locations is plotted in Fig. 6. It is clear from the figure that R^2 has a lower value for all the stations for the proposed models compared to Eq. (1). The cubic correlation gives the best performance with the highest values of R^2 for almost all the locations.

The statistical analysis shows that the best estimates of diffuse radiation are obtained from the proposed relationships compared to the model given by Eq. (1). For Bhavnagar, Kolkata, Goa, Jodhpur, Madras, Nagpur, New Delhi, Pune, Tiruvanantpuram and Vishakhapatanam both second and third order equation between diffuse coefficient and percent possible sunshine give best results. In case of Ahmadabad and Mumbai only cubic equation gives best fit. Thus in general, a third-order equation is found as the most accurate model for all these locations.

5. Conclusions

The statistical parameters show that errors in computing the diffuse component of global radiation from the widely used relations (Eq. (1)) are higher than the new proposed models. These proposed models give good agreement between the measured and computed values of diffuse radiation.

Although for most of the locations in India, square and cubic equations perform better than the relation given by Eq. (1), third order relationship between diffuse coefficient and percent possible sunshine gives most suitable fit for all the stations. Thus cubic equation can be used to estimate the diffuse component of the global radiation on a horizontal surface for the locations inside India.

The models can be applied for the computation of local values of solar radiation which is essential for the proper design of buildings, solar energy systems and a good evaluation of thermal environment within buildings.

On the basis of the models, more accurate values of diffuse radiation can be obtained which will be helpful for the prediction of clearness indices K_T. Clearness index is an important factor in the design of solar energy systems. A greater value of K_T means less diffuse radiation and more of direct radiation favoring concentrating solar systems while non-concentrating devices are needed for locations with low K_T. Clearness index is also an indicator for the installation of PV panels- the optimal tilt angle on fine days is large while for cloudy days the tilt angle is kept low. The level of K_T affects the performance of solar collectors and the installation of PV panels.

Acknowledgments

One of the author (Indira Karakoti) thanks UGC for financial support under different schemes e.g. SAP (DSA Phase III) and RFSMS. The kind advice of Dr. Bandyopadhyay, Advisor, Solar Energy Centre, MNRE, Govt. Of India, New Delhi, India are gratefully acknowledged.

References

[1] Lu Z, Piedrahita RH, Neto CDS. Generation of daily and hourly solar radiation values for modeling water quality in aquaculture ponds. Transactions of the ASAE 1998;41(6):1853–9.
[2] Machler MA, Iqbal M. A modification of the ASHRAE clear-sky irradiation model. ASARE Transactions 1985;9(1a):106–15.
[3] Cartwright TJ. Here comes the sun: solar energy from a flat-plate collector. In: Modelling the world in a spreadsheet-environmental simulation on a microcomputer. London: The Johns Hopkins University Press; 1993, 121-44.
[4] Trujillo JHS. Solar performance and shadow behavior in buildings-case study with computer modeling of a building in Loranca, Spain. Building and Environment 1998;33(2–3):117–30.
[5] ASHRAE handbook: HVAC applications. Atlanta (GA): AHRAE, 1999.
[6] Li DHW, Lam JC. Solar heat gain factors and the implications for building design in subtropical regions. Energy and Buildings 2000;32(1):47–55.
[7] Muneer T, Saluja GS. A beief review of models for computing solar radiation on inclined surfaces. Energy Conversion and Management 1985;25:443–58.
[8] Wong LT, Chow WK. Solar radiation model. Applied Energy 2001;69:124–91.
[9] Mosalam Shalout MA, Hassan AH, Fathy AM. Study of the solar radiation over Menia. Renewable Energy 2001;23:621–39.

[10] Paulescu M, Schlett Z. Performance assessment of global solar irradiation models under Romanian climate. Renewable Energy 2004;29:767–77.
[11] Mubiru J, et al. Assessing the performance of global solar radiation empirical formulations in Kampala, Uganda. Theoretical Applied Climatology 2007;87(1–4):179–84.
[12] El-Sebaii AA, et al. Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Applied Energy 2010;87:568–76.
[13] Jiang Y. Estimation of monthly mean daily diffuse radiation in China. Applied Energy 2009;86:1458–64.
[14] Noorain AM, Moradi I, Kamali GA. Evaluation of 12 models to estimate hourly diffuse irradiation on inclined surfaces. Renewable Energy 2008;33(6):1406–12.
[15] Boland J, Ridley B, Brown B. Models of diffuse solar radiation. Renewable Energy 2008;33(4):575–84.
[16] Muneer T, Younes S, Munawwar S. Discusses on solar radiation modeling. Renewable and Stainable Energy Review 2007;11(4):551–602.
[17] Orgill JF, Hollands KGT. Correlations equation for hourly diffuse radiation on a horizontal surface. Solar Energy 1977;19:357–9.
[18] Erbs DG, Klein SA, Duffie JA. Estimation of the diffuse radiation fraction for hourly, daily and monthly average global radiation. Solar Energy 1982; 28:293.
[19] Reindl DT, Beckman WA, Diffie JA. Diffuse fraction correlations. Solar Energy 1990;45:1–7.
[20] Lam JC, Li DHW. Correlation between global solar radiation and its direct and diffuse components. Building and Environment 1996;31(6):527–35.
[21] Mondel JD, Yohanis YG, Norton B. Solar radiation modeling for the simulation of photovoltaic systems. Renewable Energy 2008;33:1109–20.
[22] Soaresm J, Oliveira AP, Boznar MZ, Mlakar P, Escobedo JF, Machando AP, et al. Modeling hourly diffuse solar-radiation in the city of Sao Paulo using a neural-network technique. Applied Energy 2004;79:201–14.
[23] Elminir HK, Azzam YA, Younes FI. Prediction of hourly and daily diffuse fraction using neural network, as compared to linear regression models. Energy 2007;32:1513–23.
[24] Kalogirou SA. Optimuzation of solar systems using artificial neural-networks and genetic algorithms. Applied Energy 2004;77:383–5.
[25] Liu BYH, Jorden RC. The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. Solar Energy 1960;4:1–19.
[26] Spencer JW. A comparison of methods for estimating hourly diffuse solar radiation from global solar radiation. Solar Energy 1982;29(1):19–32.
[27] Boland JW, Scott L, Luther M. Modelling the diffuse fraction of global solar radiation on a horizontal surface. Environmetrics 2001;12: 103–16.
[28] Jacovides CP, et al. Comparative study of various correlations in estimating hourly diffuse fraction of global solar radiation. Renewable Energy 2006;31:2492–504.
[29] Page JK. The estimation of monthly mean values of daily total short wave radiation. In: Proceedings of United Nations Conference on New Sources of Energy. 1961. p. 378–90.
[30] Gupta CL, Usha Rao K, Reddy TA. Radiation design data for solar energy applications. Energy Management 1979;3:299.
[31] Modi V, Sukhatme SP. Estimation of daily, total and diffuse insolation in India from weather data. Solar Energy 1979;22:407.
[32] Mani A, Rangrajan S. Techniques for the precise estimation of hourly values of global, diffuse and direct solar radiation. Solar Energy 1983;31(6): 577–95.
[33] Gopinathan KK. Computing the monthly mean daily diffuse radiation from clearness index and percent possible sunshine. Solar Energy 1988;41(4):379–85.
[34] Mani A, Rangarajan S. Solar radiation over India. New Delhi: Allied Publishers Pvt. Ltd.; 1982.